

PRE-NORMATIVE RESEARCH NEEDS TO ACHIEVE IMPROVED DESIGN GUIDELINES FOR SEISMIC PROTECTION IN THE EU

(Support to the implementation, harmonization and further development of the Eurocodes)

A. Pinto, F. Taucer, S. Dimova



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The work reported is a deliverable within the framework of the Administrative Arrangement between DG ENTR and JRC on support to the implementation, harmonization and further development of the Eurocodes No FIF.2004740 (17.12.2004).

The report is based on two background documents:

- “Earthquake risk reduction in the European Union”, prepared by R. Spence, M. Lopes, P. Bisch, A. Plumier and M. Dolce following the workshop held in Lisbon in 2005 by , and
- “Pre- and Co-Normative research needs for Eurocode 8”, prepared by M. Fardis, former chairman of the CEN Subcommittee for EN 1998.

The contribution of the authors of the abovementioned documents to the identification and justification of key research needs is highly appreciated.

Summary

This document provides description of the pre-normative research needs to achieve improved design guidelines for seismic protection, research priorities and possible strategies for financing the research needs identified. The EU policy context is defined in the view of the Commission Recommendation to Member States on the implementation and use of the EN Eurocodes concerning the research needs to facilitate the integration into the Eurocodes of the latest developments in scientific and technological knowledge.

The background activities which headed the preparation of the document, such as the organization and participation in relevant European workshops and projects, as well as consultations with experts in the field of Earthquake Engineering, are summarized.

Two background documents have been prepared as a consequence of these activities, namely:

- “Earthquake risk reduction in the European Union”, produced by R. Spence, M. Lopes, P. Bisch, A. Plumier and M. Dolce following the workshop held in Lisbon in 2005 by , and
- “Pre- and Co-Normative research needs for Eurocode 8”, prepared by M. Fardis, former chairman of the CEN Subcommittee for EN 1998.

The background documents are summarized and analyzed herein. Aiming at to concentrate on the topics not covered in the present version of EN 1998 and to resolve the aspects concerned with safety, the following research topics are identified on the basis of the proposals in the two background documents:

- Harmonized European Seismic map;
- Provisions for the design of irregular-in-plan buildings;
- Primary vs. secondary seismic elements: Elaboration of the implications and re-evaluation of the concept;
- Seismic design rules for flat slab systems;
- Seismic design rules for prestressed concrete elements and systems;
- Design rules for masonry buildings;
- Seismic assessment and retrofitting (emphasis to masonry-infilled frame buildings);
- Seismic design of the structure-foundation-soil system;
- Seismic protection of sensitive or valuable equipment and artifacts.

The research priorities are presented in terms of the necessary time span, effort and priority of to include the results of the research into the EN Eurocodes.

Possible strategies for financing the identified research needs are discussed centering on the European Institutions, as these are the most concerned in benefiting from a research that needs to be undertaken at a European level, bringing together as far as possible the collaboration and participation of all Member States, and Industry.

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1 Introduction

The present document is a deliverable framed within the Administrative Arrangement (AA) between the Enterprise and Industry Directorate General (DG ENTR) and the Joint Research Centre (JRC) regarding support to the implementation, harmonization and further development of the Eurocodes. The deliverable is part of the activity that sets as objective (*safety objective*) to establish pre-normative research needs to foster innovation in construction products and achieve increased protection against earthquakes and fire; and belongs to the Preparation phase (Phase 1) of the present AA.

2 Commission Recommendation on the Implementation and Use of Eurocodes

A shared effort between the Commission, the Member-States and Industry is put forward by the Commission Recommendation of 11 December 2003 on the implementation and use of the EN Eurocodes for construction works and structural construction products (2003/887/EC). In particular, recommendation 6 defines the EU policy with regard to the research needs to facilitate the integration into the Eurocodes of the latest developments in scientific and technological knowledge:

6. Member States should undertake research to facilitate the integration into the Eurocodes of the latest developments in scientific and technological knowledge. Member States should pool the national funding available for such research so that it can be used at Community level to contribute to the existing technical and scientific resources for research within the Commission, in cooperation with the Joint Research Centre, thus ensuring an ongoing increased level of protection of buildings and civil works, specifically as regards the resistance of structures to earthquakes and fire.

3 Background Activities

The work described herein was prepared based on the experience matured from the organization and participation in relevant European workshops and projects, as well as consultations with experts in the field of Earthquake Engineering. These activities can be summarized as follows:

- The JRC and the UK Society for Earthquake and Civil Engineering Dynamics supported on 31 October 2005 the workshop “Earthquake risk reduction in the European Union”, hosted by the Portuguese Government (Ministers of Environment and of Public works) at the National Laboratory for Civil Engineering (LNEC) in Lisbon, and organised by the European Association for Earthquake Engineering (EAEE) and the Portuguese Society for Earthquake Engineering (SPES), with the objective of achieving a EU programme for the mitigation of seismic risks and of contributing to the definition of a set of research priorities for FP7; this workshop follows the debate that was promoted by the EC and organised by the JRC in November 2000 in Belgrade, Italy. A document titled “Earthquake risk reduction in the European Union” has been produced following the Workshop held in Lisbon.
- The former chairman of the CEN (Comité Européen de Normalisation) Subcommittee for Eurocode 8: “Earthquake Resistant Design of Structures”, Prof. Michael N. Fardis, from the University of Patras (Greece), was invited to the JRC to discuss with the staff of the ELSA Unit (European Laboratory for Structural Assessment) the research needs for Eurocode 8. Prof. Fardis had been previously commissioned by the JRC to prepare the document “Pre- and Co-Normative research needs for Eurocode 8”.
- The JRC has been active in promoting the discussion concerning the needs to achieve improved seismic protection in Europe with research institutions and Universities across Europe, through the participation in competitive projects financed by the European Union and by its involvement with the EAEE. In particular, the JRC is partner of the Integrated Project (IP) LESSLOSS for “Risk Mitigation for Earthquakes and Landslides”, that relies on the active participation of 46 European partners from both academia and industry. The LESSLOSS project addresses research issues on seismic engineering, earthquake risk and impact assessment, landslides monitoring, mapping and management strategies, improved disaster preparedness and mitigation of geotechnical hazards, development of advanced methods for risk assessment, methods of appraising environmental quality and relevant pre-normative research. The results from the research developed in LESSLOSS may contribute to answer some of the questions and needs raised in the present document; while at the same time it may propose new topics where additional research is needed.
- The experience in hosting large scale experimental studies through the European Consortium of Laboratories for Earthquake and Dynamic Experimental Research (ECOLEADER) as part of the Human Potential Programme, Transnational Access to Major Research Infrastructures – Enhancing Access to Research Infrastructures, allowed the JRC to be part in the generation of state-of-the-art know-how in the field of earthquake engineering, thus giving the necessary background to identify, together with the partners involved, the areas of research needed to improve seismic protection. Examples of projects financed by ECOLEADER contributing to Pre- and Co-Normative research are: “PsD test of a 3-storey torsionally unbalanced RC structure”, “Assessment of the seismic behaviour of reinforced concrete flat slab structures”, “Cyclic testing of two 3D Steel-concrete composite frames” and “Seismic behaviour of reinforced concrete industrial buildings”.

4 Background Documents

4.1 Earthquake risk reduction in the European Union

The document “Earthquake risk reduction in the European Union” was produced following the workshop held in Lisbon in 2005. It presents an overview of the problems of seismic risk in the European Union, establishes the reasons for concern and identifies the European dimension of the problem, and lists the actions needed to reduce seismic risk, suggesting existing EU funding mechanisms and the creation of other instruments that could be used to promote seismic risk reduction activities in Europe. In Section 5, the above referred document addresses the ‘the role of codes in the reduction of earthquake risk’ referring specifically to Eurocode 8. It is stated that the primary concern is its application in the member states, which requires a strong commitment of the National Authorities, political decisions and promotion and training for its effective applications. The following possible topics for future earthquake engineering research in Europe relevant to achievement of improved design guidelines are proposed:

- Development of a common methodology to evaluate the earthquake hazard in Europe: the research should be at least conducted at a regional scale, because the methodology depends on the tectonic context. Hazard from 475 years to 10.000 years return period should be envisaged.
- Development of assessment and strengthening methodology for more economical and safe solutions for the seismic retrofit of the existing building stock in European earthquake prone areas.
- Development of strengthening techniques of low intrusive effect for application in monuments, historical buildings and other structures.
- Seismic design and upgrading of mechanical, electric and other types of equipment used in the lifelines and industry.

4.2 Pre- and Co-Normative research needs for Eurocode 8

The document “Pre- and Co-Normative research needs for Eurocode 8” by Prof. M. Fardis deals with the research needs in the topics not- or partially covered in the present version of EN 1998. The following research needs are motivated in details:

- harmonized European seismic hazard map,
- design of irregular-in-plan buildings for torsion,
- implications and re-evaluation of primary vs. secondary seismic elements,
- seismic rules for flat slab systems,
- seismic rules for prestressed concrete elements and systems,
- design rules for masonry buildings,
- seismic assessment and retrofitting of masonry-infilled frame buildings,

- seismic design of the structure-foundation-soil system,
- seismic protection of sensitive or valuable equipment and artifacts.

The state-of-the art analysis shows, that there are other topics where research should continue, namely the issue of seismic assessment and retrofit, innovative design methods, new materials, etc. However, Eurocode 8 already covers part of these topics in the light of the most recent research findings.

The research needs identified in this document cover well those proposed in “Earthquake risk reduction in the European Union”. In this way the experience of the writers of the present generation of EN Eurocodes balances well the attitude of the research community and could serve as a basis for estimation of the pre-normative research needs to achieve improved design guidelines for seismic protection.

5 Identified Research Topics

The proposed strategy is to concentrate in the topics not covered in the present version of the code and to resolve the aspects concerned with safety. On the other side, for the topics recently introduced in the code, namely assessment and retrofit, innovative design methods, new materials, it is proposed to give room to, and monitor, their practical application and subsequently to identify needs for additional calibration and/or further developments. The list of research topics identified to achieve improved Eurocode 8 is summarized in Table 1 and presented in detail in the following paragraphs.

Table 1: List of Topics

Topic	Title
1	Harmonized European Seismic map
2	Provisions for the design of irregular-in-plan buildings
3	Primary vs. secondary seismic elements: Elaboration of the implications and re-evaluation of the concept
4	Seismic design rules for flat slab systems
5	Seismic design rules for prestressed concrete elements and systems
6	Design rules for masonry buildings
7	Seismic assessment and retrofitting (emphasis to masonry-infilled frame buildings)
8	Seismic design of the structure-foundation-soil system
9	Seismic protection of sensitive or valuable equipment and artifacts

Topic 1 - Harmonised European seismic hazard map

There is a need for development of a harmonized map of the seismic hazard in Europe that describes the seismic action in terms of 5%-damped elastic spectral values at selected natural periods.

The harmonized European seismic map should be seamless across national borders, giving Member States the freedom to set themselves the required safety level, in terms of mean return period of the seismic action for different performance levels, depending on the consequences for public safety (consequence or importance class, exposure to hazard); the maps should be consistent with the standard ground classification in Eurocode 8.

The harmonized seismic hazard maps should be based on commonly agreed sound probabilistic methodologies and on accumulated European data for attenuation of strong motions. The European hazard maps will either become an annex to EC1 or form the basis for the relevant provisions of the future National Annexes to EN 1998-1 (EC8).

Topic 2 – Provisions for the design of irregular-in-plan buildings

The results of current research show that consensus is still lacking regarding the methods for design against the effects of natural or accidental torsion, especially in the case of irregular buildings, where the extension of the methods used for the design of regular buildings has not been well established or widely accepted to date.

Research is necessary to establish how to measure the static or natural eccentricity of a building structure, and how it is affected by the changes in strength distribution. It is also important to set the grounds to move from a torsional failure criterion based on ductility ratio demands, to a more rational one based on member absolute deformations, such as drifts.

Future research should be oriented to suggest alternative design methods against natural and accidental torsion that prevent the concentration of inelastic deformation demands at the flexible side of the building in plan. A proposal is to reconsider the provisions of EN 1998-1:2004 that do not contemplate the amplification (or de-amplification, if the effects are favorable) of the natural eccentricity of specified lateral actions, to account empirically for inelastic dynamic amplification of torsional effects.

Topic 3 – Primary vs. secondary seismic elements: Elaboration of the implications and re-evaluation of the concept

For the first time in European codification EN 1998-1:2004 introduced the distinction for new buildings between members that belong to the lateral force resisting system, or 'primary members', and those that do not, or 'secondary members', where the building structure is taken in design to rely for earthquake resistance only on its 'primary seismic' elements. Although the strength and stiffness of 'secondary seismic' elements against lateral loads is neglected in the analysis for the seismic action, their contribution in resisting other actions (mainly gravity loads) should be fully accounted for. 'Secondary seismic' elements need to satisfy the rules of the other Eurocodes (EC2 to EC6), plus the special requirement of EN 1998-1:2004 that they maintain support of gravity loads when subjected to the most adverse displacements and deformations induced in them in the seismic design situation.

Research is needed to answer a number of questions and possible problem areas on the implications and practical implementation of the concept of 'primary' vs. 'secondary' elements, these are:

- The problems associated with structural modelling, where for linear elastic analysis two models should be used, one that fully includes the 'secondary seismic' members (analysis for all actions other than seismic), and one that completely neglects their contribution (analysis for the seismic action), generating inconveniences at the stage of combining the action effect of gravity loads with those of the seismic action, especially if the superposition takes place within a computational environment. In addition, when performing non-linear analysis, where the seismic action needs to be applied together with the gravity action, computational problems arise when neglecting the stiffness contribution of 'secondary seismic' elements that are part of the load bearing system of gravity loads.
- Need to clarify the effective contribution of 'secondary seismic' elements to lateral stiffness in linear analysis when performing checks of the damage limitation seismic action.
- The problems associated in determining the elastic internal forces in the 'secondary elements', necessary to check against their resistance according to the requirements of EN 1998-1:2004, when the global lateral stiffness contribution of these elements is neglected from the seismic analysis.
- The condition whereby 'secondary seismic' elements are required to remain elastic in the seismic design situation, which may lead to unfeasible designs, especially in those cases

where seismic deformations are large or the lateral stiffness of the 'secondary seismic' elements is not low.

- The consequences of modelling flat slabs and prestressed girders, which are not covered by EN 1998-1:2004, as 'secondary seismic' elements.
- The consequences related to considering some of the elements as "secondary seismic" when – due to architectural constraints – they cannot be made to conform to the prescriptive design rules for geometric configuration, dimensioning or detailing for energy dissipation and ductility.

These questions and possible problems should be resolved through a co-ordinated and imaginative program of trial applications of the concept of "secondary seismic" elements, and of research towards revising the relevant rules of EN 1998-1:2004. If such a program cannot fully resolve all problems-to-be-identified through recommended revisions of EN 1998-1, it may propose instead to abandon altogether the concept of "secondary seismic" elements for the design of new buildings, after assessing the feasibility of extending the scope of EN 1998-1 to types of elements or systems thereof not covered by EN 1998-1:2004 (e.g., flat slabs and prestressed girders) and of substituting performance-based rules for current prescriptive ones. Such an extension will remove the prime reason behind the introduction of the concept of "secondary seismic" elements. More importantly, the resulting overall improvement of EN 1998 will allow designs that will be both more economic and safer for their occupants.

Topic 4- Seismic design rules for flat slab systems

Section 5 of EN 1998-1:2004 states that its provisions do not fully cover buildings in which "flat slab frames" (i.e. frames of columns connected through flat slabs, instead of beams) are used as "primary seismic" elements. Consequently, concrete buildings designed according to Section 5 for energy dissipation may include flat slabs, provided that these are considered and designed as "secondary seismic" elements. As an alternative, concrete buildings with flat slabs may be designed considering all elements as "primary seismic" ones, but for almost fully elastic response under the design seismic action, i.e. for Ductility Class L and a value of the behaviour factor q of not more than 1.5; this alternative is recommended in EN 1998-1:2004 only for low seismicity regions.

In spite of the requirements of Eurocode 8, "flat slab frames" have performed surprisingly well in all destructive earthquakes in Greece in the past 20 years, although they had not been designed or detailed for earthquake resistance. This means that "flat slab frames" should not be considered as condemned in the event of a very strong earthquake, and that research efforts should be directed towards extending the scope of EN 1998-1 to cover "flat slab frames" as "primary seismic" elements, to the benefit of both economy and seismic safety.

Research on "flat slab frames" should be centred in the development of seismic design provisions to include rules for:

- Modelling the "equivalent frame" comprising the flat slab and its supporting columns for elastic analysis under seismic or gravity action;
- Dimensioning and detailing the slab in bending and punching shear as a function of the inelastic cyclic deformation demands imposed on the slab due to its connection to the column.

The research activities may benefit from the information available on the behaviour and performance in past earthquakes of buildings with "flat slab frame" systems and from past experimental and analytical work carried out on flat slab specimens with single columns and on complete full-scale systems subjected to earthquake-like lateral actions. Additional tests on full-scale concrete frame specimens will be needed to complete the research effort needed.

Topic 5 – Seismic design rules for prestressed concrete elements and systems

Concrete buildings designed according to Section 5 of EN 1998-1:2004 for energy dissipation may include prestressed girders, provided that these elements, as well as the columns connected to them, are considered and designed as “secondary seismic” elements, otherwise, they can be designed as “primary seismic” ones, but for Ductility Class L and a value of the behaviour factor q not higher than 1.5; this alternative is recommended only for low seismicity regions.

The experience of recent tests in Japan that have demonstrated the beneficial effect of prestressing in the cyclic behaviour of bridge piers, and the possibility of achieving plastic hinging at the ends of a prestressed beam when combining a less eccentric placement of tendons with larger quantities of ductile ordinary reinforcement at the flanges, suggests that it may be worthwhile reconsidering the present attitude in Europe against prestressing in earthquake-resistant design.

Research and Development efforts will be needed to resolve questions about the behaviour and design of prestressed concrete beams with plastic hinging and develop seismic design and detailing rules for the use of prestressing in “primary seismic” elements. This will allow such rules to appear in the next generation Eurocode 8. A strong incentive for such a drive is the world leadership – both technologically and commercially – that European prestressing systems enjoy, currently and from the very beginning of prestressing. So, European producers of prestressing materials and systems are major stakeholders in, and potential beneficiaries from, such a development and will be valuable partners in such an R&D effort.

Topic 6 – Design rules for masonry buildings

The conversion of ENV 1998-1-3:1994 to EN 1998-1:2004 entailed only few changes to the design provisions for masonry buildings. The changes were in two areas: the introduction of a disproportional high number of Nationally Determined Parameters to accommodate the large variability in masonry units and construction practices across Europe, and a thorough revision of the recommended rules for “simple masonry buildings”.

The large variability of the NDP's adopted by the different Member States, in particular those pertaining the q -factor, and the recent results obtained from the research carried out by G. Magenes, suggests that a research effort towards improving Section 9 of EN 1998-1 is needed in the following areas:

- Extend the use of the overstrength ratio due to system redundancy, and currently present in EN 1998-1:2004 for concrete, steel and composite (steel-concret) buildings, to masonry buildings as well, and calibration of its values to the structural configurations prevalent in the different Member States.
- Revision of the recommended rules for the design of “simple masonry buildings”, especially with regards to the recommended minimum wall area, which at present are inconsistent with the experience derived from shake-table tests and post-earthquake field surveys, and from the results of non-linear analysis.
- Revision of the limits given by EN 1998-1:2004 for the redistribution of shears obtained from elastic analysis, which do not have a rational basis for masonry, in particular for unreinforced masonry: much higher redistributions are possible in masonry buildings at very limited additional deformations.
- Re-evaluation and strengthening of the provisions of EN 1998-1 for masonry buildings for the prevention of the out-of-plane collapse (currently an NDP), in particular the limits to slenderness ratios of primary and secondary elements.

The research may benefit from the already existing experimental and analytical data on the seismic response and performance of masonry buildings, as well as from other codification efforts (notably the new Italian code) more recent than the technical completion of the EN

1998-1:2004. Experimental (mainly shaking-table) and analytical research (mainly nonlinear, static or dynamic) will need to be performed to fill in the gaps in knowledge regarding the seismic response and performance of masonry buildings; emphasis may need to be placed on buildings with masonry materials or construction typologies that differ significantly from those common in most highly seismic regions of Southern Europe.

Topic 7 – Seismic assessment and retrofitting (emphasis to masonry-infilled frame buildings)

The provisions of EN 1998-1:2004 may be considered as safe for the design of new buildings that have masonry infills, as these are taken as a second line of defence and a source of overstrength, while the seismic action effects for the design of the structure are not reduced due to the beneficial effects of infills.

It might be argued that these provisions are not rational or cost-effective, as they do not account for an influence of the infills, which is generally important and normally beneficial. In fact, new research may be needed to explicitly include infills in the model used for seismic analysis and to verify their capacity against the demands of the seismic action. However, the costs to be incurred due to the additional design effort and the quality assurance for the masonry-infills may outweigh any savings in the concrete or steel members of the structural system, placing the revision of the provisions of EN 1998-1:2004 not high in the list of priorities.

Conversely, accounting for the effects of masonry infills on seismic performance becomes of outmost importance when the structural system itself has little engineered earthquake resistance, as is often the case in existing buildings that often survive strong earthquakes thanks to their masonry infills. However, EN 1998-3:2005 (i.e., the part of Eurocode 8 for seismic assessment and retrofitting of existing buildings) does not include any provisions to help the designer account for the infills in the assessment of an existing building and in the design of its seismic retrofitting. Therefore, there is an urgent need to enlarge the scope of EN 1998-3, with provisions for:

- Modelling individual infill panels for the analysis.
- Verification of individual infill panels for the seismic action effects computed for them
- Upgrading of strength, stiffness and/or deformation capacity of infill panels, so that the retrofitted building can better profit from them
- There are a few open issues and questions to be resolved through research, to reach the point that masonry infills can rationally and efficiently be used in seismic assessment and retrofitting of existing buildings:
- Simple rules should be developed for the establishment of the force-deformation curve of infill panels under cyclic loading, including the effect of openings of various shapes, sizes and locations within the panel.
- The material properties on which key parameters of the above force-deformation curve of infill panels depend should be identified. Moreover, lists with default values of these properties should be developed, for various types of masonry, regions in Europe and periods of original construction.
- Guidance should be developed for the upgrading of infills into engineered structural components, for the purposes of seismic retrofitting.

By far the most challenging open issue to be resolved through this research is that of the effect of openings on the cyclic force-deformation behaviour of masonry infills, depending on the shape and size of the opening(s) and their location within the infill panel.

Topic 8 – Seismic design of the structure-foundation-soil system

Similar to all other modern seismic codes in the world, Eurocode 8, in all its Parts, considers the structure separately from the soil and from the foundation; soil-structure interaction is taken into account to a limited extent and only in special cases.

In the future, Eurocode 8 should address the design and verification of the structure, its foundations and the soil as a system and not as isolated parts. For this, research will be needed in the following areas:

- Assessment of the effects on the superstructure of (important) phenomena in the soil (large soil deformations), or at its interface with the structure (e.g. sliding and/or uplift/rocking).
- Evaluate the implications of considering the structure, its foundations and the soil as a system, leading to alternative cost-effective seismic design concepts that will allow - under certain conditions - concentration of nonlinearity and energy dissipation in the soil or in the foundation, as well as a change in the ductility demand in the superstructure, leading to a modification of the recommended values of the behaviour factor, q .
- Extend the research work to structures developing large interaction with the surrounding ground, like underground facilities (including tunnels, buried storage systems, oil wells, etc.), which are currently outside the scope of Eurocode 8.

The development of concepts and procedures for the seismic design and verification of the structure, its foundations and the soil as a system, is a new idea and a longer-term objective, not expected realistically to be covered for the 2nd generation of Eurocode 8, even if intensive R&D work were to start tomorrow.

Topic 9 – Seismic protection of sensitive or valuable equipment and artifacts (Partial Isolation)

Many buildings in developed countries house valuable contents or equipment that may suffer heavy damage, or even total loss, under earthquakes that the structure of the building is designed to safely sustain. Other than the concern for elements that pose a risk to life, to the structure itself or to the functioning of critical facilities, EN 1998-1 does not have specific provisions for the protection of building contents that are sensitive to accelerations, regardless of their value or importance.

EN 1998-1 provides a single approach to seismic isolation of buildings: full isolation of the entire building, by providing an isolation system between the foundation and the superstructure. According to EN 1998-1:2004, the superstructure of the so-isolated building should be designed to remain elastic under the “design seismic action”. As a matter of fact, proposals were made (from Italy) to enlarge the scope of Section 10 of EN 1998-1 to include “partial isolation” of buildings. These proposals were not considered, as they came very late in the process of drafting EN 1998-1 (essentially after its technical contents had been finalized). Nonetheless, providing - through isolation - enhanced protection only to the part of the building that supports sensitive and valuable equipment or artifacts (e.g., works of art) may be a much more effective approach than full isolation at the base of the entire building. Moreover, such an approach may not only achieve isolation of the sensitive and valuable equipment or artefact against the horizontal components of the seismic action and of the structural response to it: it may also provide the means of protecting it from the vertical component (or other vertical vibration that causes fatigue, e.g. due to traffic) and from overturning due to any rotational component (about a horizontal axis) of the seismic action, or of the response at the point where the equipment or artifact is supported.

The provisions of EN 1998-1 should, therefore, be supplemented with:

- Rules for the development of horizontal and vertical “floor spectra” at various levels of the building, as input for the full seismic design of equipment or artifacts supported on the structure (with or without isolation of the equipment or the artifact); floor spectra should take into account the nonlinearity of the response of the supporting structure;
- Design rules for the protection of sensitive and valuable equipment or artifacts through horizontal and vertical isolation of the very part of the structure supporting this equipment or artifact (including prevention of overturning)
- Design concepts and guidance for enhanced seismic protection of sensitive and valuable equipment or artifacts supported by building structures.

6 Research Priorities

The research priorities to carry out the research described in the previous section are presented in Table 2 in terms of the necessary time span duration, effort and priority of including the results of the research into the EN Eurocodes.

The time span duration is given in terms of the number of years to complete the research; the effort gives an indication of the difficulty, as well as the amount of human and economical resources necessary for the successful completion of the research (i.e., a high effort is associated to areas where experimental testing of large scale structures is needed); whereas the priority reflects the urgency of resolving and answering the questions exposed in the previous section that would give a significant contribution towards improving the current versions of the Eurocodes.

Table 2: Duration, Effort and Priorities

Topic	Duration	Effort	Priority
1	3 - 4 years	Medium	Medium - Low
2	3 - 4 years	Low	High
3	3 - 4 years	Low	High
4	3 - 4 years	Medium	Medium
5	3 - 4 years	Medium - High	Medium
6	3 years	Medium	High - Medium
7	3 - 4 years	Medium	High - Medium
8	2nd - 3rd generation of EN's	High	Low
9	3 years	Medium	Medium

Table 3 presents the list of Eurocodes that are affected by each topic, while Table 4 gives a list of the actors that will be participating in the research activities, be from academia, research, design practice and/or industry.

Table 3: Concerned EN's

Topic	Concerned EN
1	EN 1991 or EN 1998-1
2	EN 1998-1:2004
3	EN 1998-1:2004
4	EN 1998-1:2004
5	EN 1998-1:2004
6	EN 1998-1:2004
7	EN 1998-1:2004, EN 1998-3:2005
8	EN1997, EN 1998
9	EN 1998-1:2004

Table 4: List of Actors

Topic	Actors	
	Research / Academia / Practice	Industry
1	Engineering seismology	-
2	Earthquake engineering: seismic design and codification	-
3	Earthquake engineering: seismic design and codification	-
4	Earthquake engineering: seismic design and codification, testing of near to full-scale concrete systems	-
5	Earthquake engineering: seismic design and codification, testing of near to full-scale concrete systems, including prestressing	European manufacturers of prestressed materials and systems
6	Earthquake engineering: seismic design and codification, shake table testing of near to full-scale masonry buildings	Manufacturers of masonry units and systems from various European countries (highly and less seismic)
7	Earthquake engineering: seismic design and retrofitting, testing of materials	Manufacturers of masonry units and systems from various European countries (highly and less seismic)
8	Structural and geotechnical (earthquake) engineering: academia, research and design practice	
9	Academia, the design and consulting community and industry	European manufacturers and consultants in seismic protection through isolation and dissipation are among the world leaders in innovation and field applications and will be very important partners

Table 5 gives a description of the type of research activities needed to complete the research, which may be analytical, experimental or a combination of the two.

Table 5: List of Activities

Topic	Activities
1	Analysis of strong motion data and catalogue of active faults and historical earthquakes in Europe
2	Nonlinear seismic response analysis of buildings
3	Analytical work
4	Analytical work, and quasi-static cyclic and pseudodynamic testing of near to full-scale concrete frame systems
5	Analytical work, and quasi-static cyclic and pseudodynamic testing of near to full-scale concrete frame systems, including prestressed beams
6	Analytical work, shaking-table tests of near to full-scale masonry buildings
7	Analytical work, simple tests on masonry material
8	Conceptual developments, workshops, brainstorming, iterations of designs and seismic response analysis of simple systems, trial applications
9	Conceptual developments, as well as analytical/numerical work and possibly experimental verification

7 Possible Strategies for Financing the Identified Research Needs

The research needs identified in the above sections may be funded at the levels of either National or European Institutions with the support and participation of Industry, when relevant. The discussion is centred only on the European Institutions, as these are the most concerned in benefiting from a research that needs to be undertaken at a European level, bringing together as far as possible the collaboration and participation of all Member States.

The main source of funding would come from the European Commission, in particular:

- from DG RESEARCH through the Seventh Framework Programme (FP7), which will finance research and development in Europe during seven years, from 1 January 2007 to 2013, and
- from DG ENTR for those topics where minimum safety to users and public, and realization of the Single Market (competitiveness) are of primary concern.

FP7 is organised into four programmes: Cooperation, Ideas, People and Capacities. It is in the first programme of Cooperation where most of the funding would be generated to finance the topics identified in the present paper; the two last programmes of People and Capacities would also contribute as a source of funding, but to a minor extent. In this context, the present research priorities should be conveyed to DG RESEARCH.

Under the Cooperation programme the Joint Technology Initiatives will be created on the basis of the work undertaken by the European Technology Platforms, where the scope of an RTD objective and the scale of the resources involved justify covering one or a small number of selected aspects of research in their field, combining private sector investment and national and European public funding. It is through the European Technology Platform, with the initiative of the construction industry, that research and development priorities along the lines of the topics presented in this paper can be defined. In fact, the European Construction Technology Platform (ECTP), which was launched on October 2004, is also an appropriate place to introduce the research needs identified in the present paper.

Another line of funding could be sought in DG ENTR, especially for those topics where minimum safety to users and public and realization of the Single Market (competitiveness) are of primary concern. In this case, emphasis must be placed in stressing the need and advantage for Europe of achieving thereafter harmonization of the European Standards, and of improving those areas of the Eurocodes where important questions still need to be resolved. The case of the harmonised European seismic hazard map for definition of the design seismic loading in Eurocode 8 is a typical example of a needed research priority viewing at harmonized approaches to the modelling of seismic activity, the earthquake cycle on active faults, the relationship between strong or large historical earthquakes and active faults, and the mapping of capable and active faults.

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Abstract

This document provides description of the pre-normative research needs to achieve improved design guidelines for seismic protection, research priorities and possible strategies for financing the research needs identified. The EU policy context is defined in the view of the Commission Recommendation to Member States on the implementation and use of the EN Eurocodes concerning the research needs to facilitate the integration into the Eurocodes of the latest developments in scientific and technological knowledge. The background activities which headed the preparation of the document, such as the organization and participation in relevant European workshops and projects, as well as consultations with experts in the field of Earthquake Engineering, are summarized. Two background documents which have been prepared as a consequence of these activities are summarized and analyzed.

The research priorities are presented in terms of the necessary time span, effort and priority of to include the results of the research into the EN Eurocodes. Possible strategies for financing the identified research needs are discussed centering on the European Institutions, as these are the most concerned in benefiting from a research that needs to be undertaken at a European level, bringing together as far as possible the collaboration and participation of all Member States, and Industry.

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